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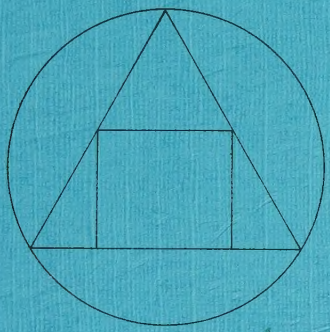

Strain Ageing in Welds in Structural Steels

Sten Bergh

Lund 1973

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Strain Ageing in Welds in Structural Steels

Av

Sten Bergh

Tekn. lic., Vrml

Akademisk avhandling

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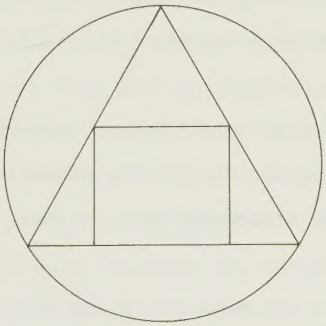


Strain Ageing in Welds in Structural Steels

Sten Bergh

Lund 1973

The following papers are included in this dissertation:

1. Bergh, Sten. Influence of carbon content on strain ageing in annealed rimming deep-drawing steels at different low nitrogen contents. Jernkont. Annaler 150(1966) p 249-273.

2. Bergh, Sten. Deformationsåldringskänsligheten i svetsförband. Utveckling av lämplig provningsmetod samt studier av deformationsåldringskänsligheten i svetsförband av mikrolegerade svetskonstruktionsstål.
   The susceptibility to strain ageing in weldments.
   Development of appropriate testing methodology and a study of the susceptibility to strain ageing in weldments in micro-alloyed structural steels.
   Trans. Production and Materials Engineering Division, Lund Technical University, Lund 1973.

Strain ageing in welds in structural steels

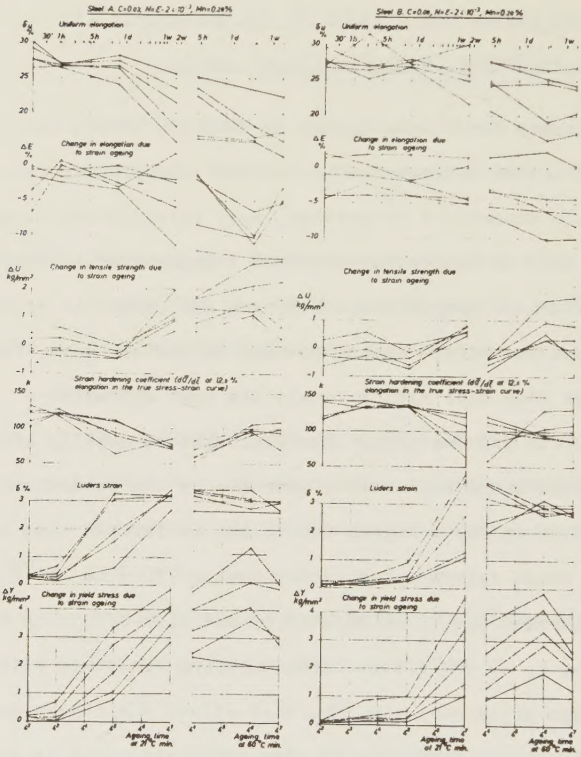
The interaction between carbon and nitrogen in rimming steels. Development of a test method and a study of the susceptibility to strain ageing in weldments in micro-alloyed steels.

The conditions necessary for strain ageing in ferritic steels are free interstitials (in practice nitrogen and/or carbon) and plastic deformation. Ageing implies that a material's properties, e.g. strength and toughness change slowly when held at ambient or elevated temperature. An increase in temperature accelerates the process. Nitrogen and carbon in solution in the ferrite affect the strain ageing process in similar ways. This is due to the fact that they have approximately the same diffusion coefficients in ferrite and that they lock dislocations equally effectively. In conventional unstabilized mild steels nitrogen is the predominant cause of strain ageing since it has a higher solubility in ferrite than carbon in the temperature range relevant for strain ageing (20 - ca 250°C). The ageing caused by nitrogen can be eliminated by addition of strong nitride formers, e.g. Al and V, to the steel. Other alloying additives with affinity for nitrogen or carbon, e.g. Mn, also affect the strain ageing process. The heat treatment condition is also important since it greatly affects the amount of interstitials in solution.

Experience of the production of unkilled deep-drawing sheet (steel with the approximate composition 0.03 - 0.08 % C, 0.003 - 0.006 % N and ~0.25 % Mn has shown that charges in the higher range of carbon content strain age more slowly than those in the lower range.

The first paper describes a laboratory study of the process of strain ageing in unstabilized deep-drawing sheet with two carbon levels, 0.03 and 0.08 %, and five different nitrogen contents between 0.5 - 2.4 x 10^{-3} %.

The results for the mechanical properties during the strain ageing process are shown in Fig. 1.



nitrogen content, %

0,5 x 10^{-3}

0,7 "

1,1 "

1,5 "

2,4 "

Fig. 1 - (Fig. 2, paper 1). Changes in tensile properties of two low carbon steels for five different nitrogen contents after strain ageing. Prior deformation 8 %. The shortest ageing time at 60°C has been chosen to somewhat overlap the longest time at 21°C.

It is apparent from the figure that the strain ageing develops more slowly and to a lesser degree on raising the carbon content from 0.03 to 0.08 % for all nitrogen contents. The same effect has been confirmed using internal friction measurements. A conceivable explanation for this is that cementite has some nitrogen solubility. An increase in the carbon

content, i.e. an increase in the amount of cementite, would lower the amount of nitrogen in solution in the ferrite, thus causing a decrease in the strain ageing. Another mechanism was suggested by Baird in 1971 (ref. 3, paper 2). According to this theory the cause is a coupling between carbon and manganese contents via the oxygen in the molten steel. It is known that Mn has a nitrogen binding effect.

The second paper describes strain ageing studies in weldments in carbon-manganese constructional steels, both unstabilized and stabilized with various grain refiners, viz. steels with the base composition 0.10 - 0.20 % C, ca 0.30 % Si, 1.0 - 1.5 % Mn and ~0.010 % N. The stabilizers used were Al, V, Nb, and Nb + Al. A considerable part of the research work has been devoted to developing a test method suited to the aims since such a method was lacking.

These studies, described in the second paper, are to a certain extent a development of the more general study of the process of strain ageing which emerged in the first paper.

The weld metal and its immediate vicinity, the heat-affected zone, undergo an inhomogeneous thermomechanical treatment in conjunction with welding which can to various degrees both bring bound nitrogen and carbon into solution in the ferrite and develop a heterogeneous state of deformation. In this way the conditions for strain ageing have been created to varying degrees. A weldment is also characterized by large differences in structure from the cast structure in the weld metal to pure rolled structure outside the heat-affected zone. In this zone the phase development, grain size and degree of precipitation, etc., all vary. All these factors affect the final properties, and in particular the toughness, of the weldment.

In order to find ways to improve the properties of weldments one must

be able to distinguish and isolate the effects of the various factors. This can either be done by studying relevant weldments or by carrying out simulation experiments.

The aim of the research work described in the second paper has been to try to isolate in a simple and unambiguous way, the effect of strain ageing on the mechanical properties in real weldments.

Methods at present available are not especially suitable for such studies in materials as complex as weldments. Internal friction measurements are also difficult to carry out in practice in this case. The interpretation is also difficult when elements other than carbon and nitrogen are present in the ferrite. In the chemical analysis of carbon, only the total content can be determined. For nitrogen in Al-stabilized steels the amount of interstitial nitrogen can be obtained as the difference between total nitrogen and nitrogen bound to aluminium as determined by the esterhalogen method. The accuracy for normal works analyses is not, however, greater than $\sim 2 \cdot 10^{-3}$ %, a value which in itself is sufficient to cause severe ageing. Tensile testing of aged specimens gives mean values for relatively large volumes. Impact testing is conceivable but it demands large series of impact test specimens. It is also difficult to localize the notches correctly relative to the various zones of the weldment. The scatter is large. The newly developed method involves microhardness measurements across the weldment in the upset condition before and after ageing treatment (see Fig. 2).

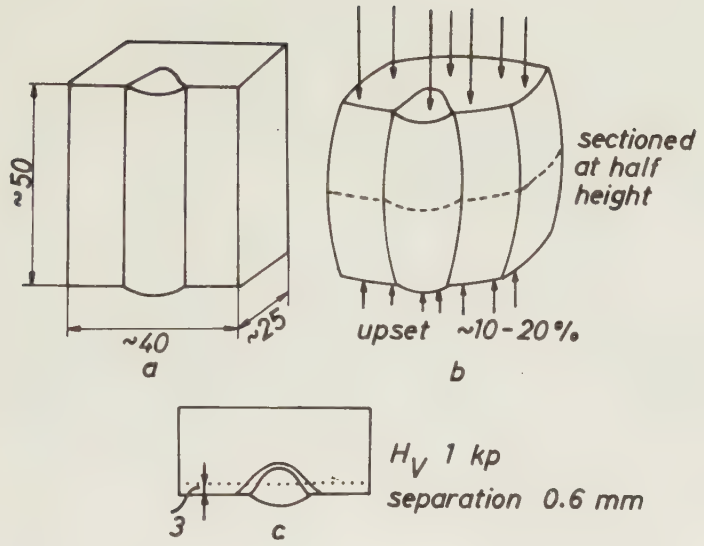


Fig. 2 - (Fig. 6, paper 2). Schematic diagram of the three steps used during strain age testing. a) sample removal from weldment, b) upsetting (ca 15 %) and sectioning of specimen, c) hardness measurement (H_v 1 kp) along a line below the surface (say 3 mm) across the base metal, heat-affected zone and weld metal.

In order to be able to differentiate between the effects of nitrogen and carbon on the strain ageing the two ageing temperatures 60 and 200°C have been chosen. The lower temperature, 60°C, implies accelerated room temperature ageing. Considering the high temperatures and fast cooling which arise in the inner regions of weldments, a certain solution of carbon can be anticipated. For this reason the ageing temperature 200°C has been chosen, a temperature which certainly causes solution of carbon. A critical physical metallurgical discussion of the test procedure shows that it should be particularly suitable for weldments. The measured quantity, hardness change, which is a secondary or late ageing criterion

is relatively independent of grain size and deformation direction. It also permits a relatively long time for sectioning and preparation of the specimens after upsetting ca 15 %. This is important from the practical aspect. For the relatively high degree of upsetting, 15 %, uniform deformation is obtained and, furthermore, a small scatter around this value has a negligible effect on the result of ageing.

The newly developed test method has been used for determination of the sensitivity to strain ageing in the previously mentioned grades of carbon-manganese constructional steels in submerged arc surface welds. Fig. 3 a and 3 b show the hardness variation for various stages of the test for one of the steels.

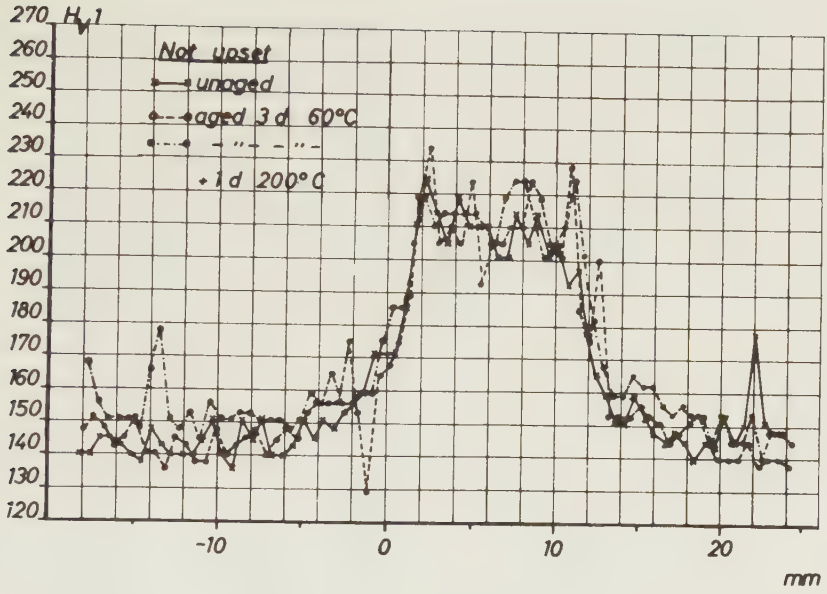


Fig. 3 a

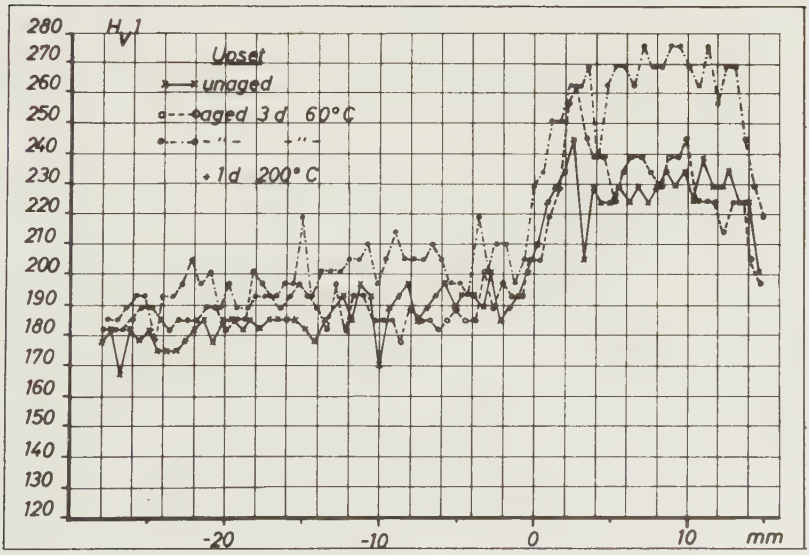


Fig. 3 b

Fig. 3 - (Fig. 7, paper 2). Diagrammatic summary of the hardness in unaged and aged stages. a) Unupset specimen b) 15 % upset specimen. Material: Nb + Al-grain refined carbon-manganese steel.

Based on the maximum temperatures which have been measured in the various parts of the weldments during test weldings, the ageing values which were obtained for the 200°C-ageing have been taken to characterize weld metal and the inner regions of the heat-affected zone. The base material and the outer parts of the heat-affected zone which have never exceeded 100°C are characterized by the 60°C-ageing, i.e. the pure nitrogen ageing. The strain ageing sensitivity for all steels examined are summarized in Fig. 4.

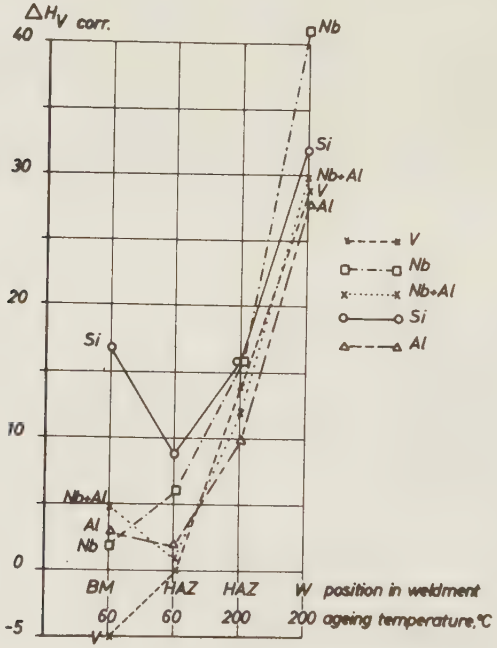


Fig. 4 - (Fig. 17, paper 2). Survey of the strain ageing sensitivity in different parts of weldments for stabilized and unstabilized carbon-manganese steels. (BM = base material, HAZ = heat-affected zone, W = weld metal. For the base material the uncorrected hardness increase has been used.)

The results show that the sensitivity to strain ageing in mixed weldments and neighbouring parts of the heat-affected zone is high and independent of the degree of stabilization and choice of stabilizer in the base material. The carbon ageing is considerable in this region. These results must be considered to be important. As expected, only the unstabilized steel shows marked sensitivity to strain ageing in the outer regions of the heat-affected zone and in unaffected base material.

Since deterioration in toughness is the most important change in properties in weldments an attempt has been made to transfer measured hardness changes to increase in the charpy-V transition temperature. In this work relations published concerning the connection between yield stress change and transition temperature change during precipitation hardening in microalloyed steels have been used. Thus in this case a hardness increase of ten units corresponds to an increase in the transition temperature of 5 - 6°C. The order of magnitude of the deterioration in toughness in weldments calculated in this way are in agreement with the expected changes.

Analysis of the test results for the weldments examined in constructional steels are in agreement with what can be expected on the basis of physical metallurgical reasoning.

The simple test procedure developed can thus be considered to perform an essential task in weld research.

Conclusions

The strain ageing caused by nitrogen has been studied in unstabilized deep-drawing sheet for two different carbon levels. It has been found that an increase of the carbon content from 0.03 to 0.08 % causes the strain ageing to develop both more slowly and to a lower level. The cause is possibly that cementite presents some solubility to nitrogen (paper 1).

The sensitivity to strain ageing in various parts of weldments in a series of modern welding constructional steels has been studied using a test procedure especially developed for this aim (paper 2).

It has thus been found that the sensitivity to strain ageing is large in mixed weldments and neighbouring regions of the heat-affected zone independent of degree of stabilization and choice of stabilizer in the base material. The carbon ageing is larger here than is usually noted. In the outer regions of the heat-affected zone and in unaffected base material the stabilized steels differ in a positive way from the unstabilized. A qualitative estimate of the changes in toughness during strain ageing can be obtained from the hardness differences measured during testing with the aid of empirical relations published in the literature. According to this a hardness increase of ten units due to strain ageing causes an increase in the charpy-V transition temperature by approximately 6°C.

The test method can to a certain extent differentiate between the types of ageing (carbon or nitrogen) and grade the sensitivity to strain ageing in the various parts of the weldments. It comprises a valuable complement to methods of measurement used in weld research and should therefore be suitable as a standard method.

AB LUNDA-KOPIA, LUND